Biogeophysical Effects of Anthropogenic Land Cover Change During the Last Millennium

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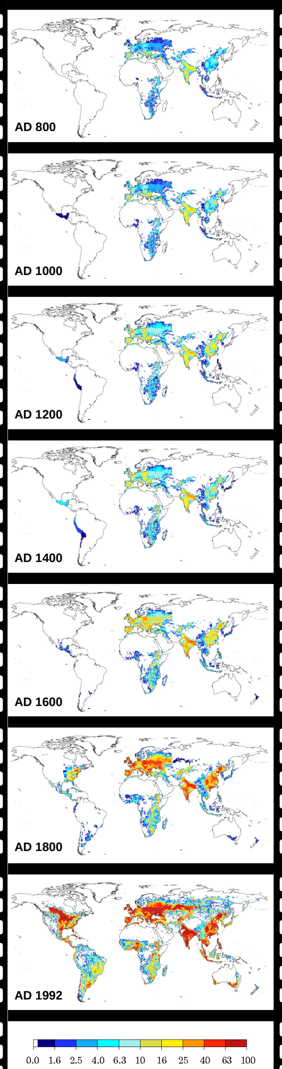

Fig. 2: Cropland (fraction of grid cell) AD 800-1992

Introduction

Anthropogenic climate change is generally thought to have begun with the industrial revolution. Human impact on the environment, however, started much earlier: thousands of years ago, land was already transformed to cropland and pasture. It is acknowledged that anthropogenic land cover change at today's scale has a significant impact on local to global climate. Yet, the effects of pre-industrial agriculture are not well understood [1].

A main obstacle has been the lack of quantitative data on historical agricultural activity prior to AD 1700 and a detailed analysis of its effects on climate. This contribution presents advancements in both aspects. We present a detailed reconstruction of anthropogenic land cover change for the last millennium [2]. With this we calculate the historical changes in radiative forcing. Finally, we assess the full biogeophysical climate response of anthropogenic land cover change in a high-resolution atmospheric GCM.

1. Reconstructing historical land cover

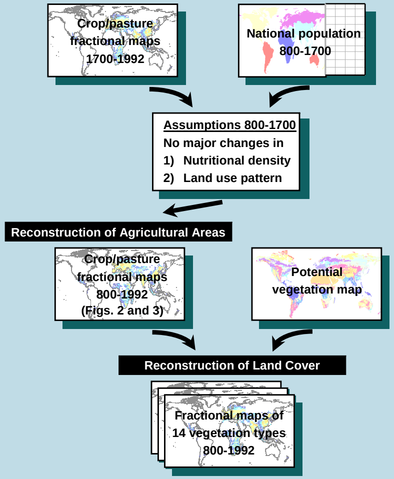

Fig. 1: Method for reconstructing historical agricultural areas and land cover

We reconstruct fractional maps of the land use types crop, C3 and C4 pasture for AD 800-1992 at 0.5 min resolution (Fig. 1). After 1700 we adapt data from SAGE [3] and HYDE [4]. For earlier times, we use population as a proxy for agricultural activity. The above stated assumptions are applied on national level and are regionally modified where necessary. The result is a millennium reconstruction of agricultural areas (Figs. 2 and 3). Combined with a map of potential vegetation [3] we estimate global historical land cover change [2]. We assess the uncertainty range associated with our approach in two additional datasets.

2. History of radiative forcing from albedo changes

We calculate a time series of instantaneous radiative forcing ΔF from changes in albedo, by coupling the land surface scheme JSBACH to the global climate model ECHAM5. Our results are in line with previous studies for the recent centuries that are covered by former land cover data [5]. For pre-industrial times, our results show that energy balance was significantly influenced by human activity already a millennium ago. Regional monthly values of radiative forcing are as low as –2.5 W/m² in AD 800. The ancient centers of agriculture in the Mediterranean, India, and China impose a negative forcing throughout history (Fig. 4).

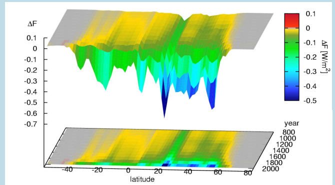

Fig. 4: Zonally averaged instantaneous radiative forcing

The interplay of incoming radiation, type of land cover conversion, and background albedo causes a complex pattern of ΔF (exemplarily shown in Fig. 5a). Strong regional dynamics are observed as a result of political and social changes, and events such as the Black Death epidemic in Europe (starting AD 1347) leave a distinct fingerprint in forcing history (Fig. 5b).

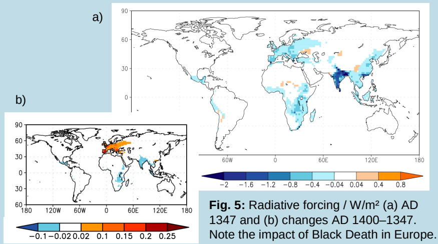

Fig. 5: Radiative forcing / W/m² (a) AD 1347 and (b) changes AD 1400–1347. Note the impact of Black Death in Europe.

References

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[6] For more information see: http://www.mpimet.mpg.de/en/wissenschaft/working-groups/millennium.html

3. Biogeophysical climate response

We estimate the impact of anthropogenic land cover change by biogeophysical effects on climate. The climates under present-day and potential land cover are compared in two 100-year simulations with ECHAM5 at T63 (~2°) resolution. We find a cooling over areas of land cover change in the northern midlatitudes (Fig. 6d), reaching –1.5 K in early spring. In this region we observe a decrease in net radiation due to increased albedo (Fig. 6a) throughout most of the year. In tropical regions, temperature rises due to a decrease of latent heat flux and cloud cover (Fig. 6b,c).

The globally averaged effect of agricultural expansion is a slight cooling (–0.02 K over areas of land cover change), which is consistent with previous studies where the surface albedo change is the dominating force [5]. Over all land area, the radiative forcing from changes in surface albedo is –0.47 W/m² and thus similar to the changes in latent heat flux (–0.43 W/m²). Net solar radiation is reduced by –0.57 W/m² over land.

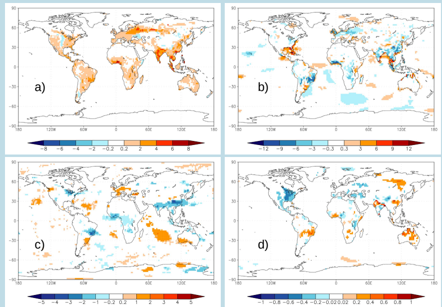

Fig. 6: Changes in climate: simulations with land cover 1992 minus potential vegetation (a) albedo / % (b) latent heat flux / W/m² (c) cloud cover / % (d) surface temperature / K. Shown are changes that are significant on the 95% level.

Summary

- A high-resolution land cover reconstruction for the last millennium has been developed [2].
- Calculations of radiative forcing show that regional energy balance was significantly influenced by human activity already a millennium ago. For certain times and regions, the energy balance is altered by historical events such as Black Death.
- The changes in energy balance suggest an anthropogenic influence on regional climate before the industrial era began.
- The biogeophysical global climate response of agricultural expansion until today is a small cooling effect in our study. The changes in albedo are important in the northern midlatitudes and lead to a cooling, whereas changes in evapotranspiration and cloud cover lead to a warming in the tropics.
- In the future we will focus on fully coupled transient climate simulations over the last millennium [6].

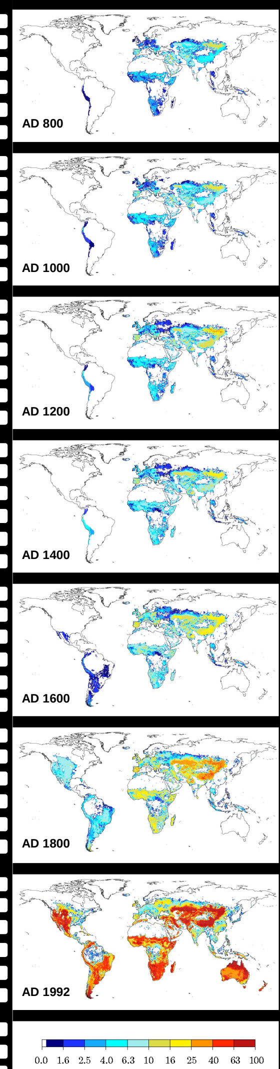

Fig. 3: Pasture (fraction of grid cell) AD 800-1992

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